PALAEOZOIC GEOLOGY OF THE COOLEMAN CAVES DISTRICT, NEW SOUTH WALES.

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(Plates iii–iv; one Text-figure.)

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Synopsis.

Stratigraphy and structure of Silurian strata, including fossiliferous limestones of Cooleman Caves, are described, as well as Ordovician sedimentary rocks and Devonian lavas. Brief notes on granitic rocks and minor intrusives are given.

Introduction.

The limestone of Cooleman (formerly Coolalamine) Plain was first reported on by the Rev. W. B. Clarke (1860), and fossils collected by Clarke from this area were described by de Koninck (1876-77). Further geological notes were published in a report on the caves by Leigh and Etheridge (1894).

But it was not until recent years that any attempt was made to map the district geologically. Ivanac and Glover (1949) and Walpole (1952) carried out reconnaissances and produced maps, and in 1956 Snowy Mountains Hydro-Electric Authority geologists began detailed work near Pocket Saddle in connection with the proposed Tantangara Reservoir (Newbery, 1956). The writer extended mapping to the Cooleman and Currango Plains and adjacent ranges during the summers of 1956-7 and 1957-8 (see map, Pl. iii).

Physiography.

The western part of the area consists of broad, open plains with a general elevation of 4,200 feet, bounded by wooded ridges which rise gradually to a maximum of 5,200 feet (Pl. iv, fig. 1). Cooleman Plain, remarkably level where undissected, is drained by Cave Creek, a major tributary of the north-flowing Goodradigbee River. Close to the southern margin of the area is the Murrumbidgee-Goodradigbee divide. It is a wooded, east-west ridge, broken by two low saddles. The western saddle, Blue Waterhole Saddle, lies between Cooleman and Currango Plains, the eastern one, Pocket Saddle, which is almost flat, links Currango Plain with the Goodradigbee Valley.

The Goodradigbee River (known as Murray Creek in its upper reaches) rises in the Bimberi Range and flows through granite in a general north-north-west direction. On entering resistant Ordovician quartzites, it flows west through a gorge and then pursues a northerly course through less resistant Silurian slates and limestones.

In this way it passes close to Pocket Saddle and has cut a valley with a base over 200 feet below the saddle.

The Goodradigbee Valley and the country east of the Blue Waterhole, with V-shaped valleys and steep-sided gorges, contrasts with the "plain and marginal ridge" topography of the rest of the area (Pl. iv, figs. 3, 4).

Evidence of the 4,200 feet level is still visible on either side of the Goodradigbee Valley downstream from Pocket Saddle. Much of this level has been preserved by a covering of lavas, which still remains on the Rolling Grounds Spur.

Scattered outliers of Devonian lavas indicate that the topography of Cooleman Plain is more or less the same as in Devonian times, the level limestone plain having been formed before the outpouring of the lavas which gave rise to the surrounding ridges.

Remnants of a higher level between 5,000 feet and 5,200 feet are widespread, including Black Mountain and the Gurrangorambla Range north-west of Blue Waterhole Saddle.

Stratigraphy.

Ordovician.

Rocks classed provisionally as Ordovician are found on the eastern and western margins of the area. The more important exposures are on the east, where quartzites and slates extend south from the Rolling Grounds Spur and are known to be continuous with the Ordovician Nungar Beds (Newbery, 1956; Stevens, 1958) 10 miles to the south.

The beds consist mainly of quartzite and slate with sandy slates and siltstones. The slates are usually buff or grey and the quartzites white, but black cherty types are not uncommon. The rocks are strongly cleaved and show much contortion within the beds. On the east they are bounded by granite, and to the west there is an indistinct junction with Silurian slates of the Pocket Beds.

Another north-south belt of sediments of probable Ordovician age occurs in the north-west of the district, apparently underlying Silurian limestone. These sediments are mostly fine-grained, poorly bedded sandstones, similar to rocks regarded as uppermost Ordovician in the Nungar area.

Silurian.

The majority of the sedimentary rocks are of Silurian age, including large limestone belts, with formations of cherts, fine-grained sandstone, siltstone and shale.

Rapid facies changes from west to east complicate stratigraphical nomenclature and sequence determination. The Cooleman Limestone, which is a thick and important formation in the west, is represented by the Pocket Beds (mainly slate and limestone) in the east, while the overlying Blue Waterhole Beds change from siltstone, shale and sandstone in the west through cherts and sandstone to cherts (and perhaps limestone) as one proceeds east.

Table 1.
Silurian sequence.

Area	West	Central	East
2.	Blue Waterhole Beds		3. Wilkinson Limestone
	(Siltstone, shale, sandstone)	(chert, sandstone)	2. Blue Waterhole Beds (chert, limestone)
1.	Cooleman Limestone		1. Pocket Beds

(*a*) *Cooleman Limestone.*

This formation, named by Walpole (1952), is exposed on Cooleman Plain outcropping over an irregular, arcuate area, which has been strongly dissected by Cave Creek in the north-central parts to form Cooleman (Clarke's) Gorge.

The limestone has been folded into broad, plunging folds and appears to be the oldest Silurian formation. Near Blue Waterhole Saddle a few feet of chert and micaceous tuff underlie the limestone, but it is not clear whether more limestone underlies these sediments and is covered or intruded by adjacent granophyre. In most other places on the S.W. margin the limestone is bordered by younger dacite lavas or granophyre.

The limestone is generally massive with occasional chert beds and thin shaly layers; it is, like most lower Palaeozoic limestones in New South Wales, quite pure, except for dolomitized zones which tend to follow joint planes. Near intrusive rocks and lava flows it has been silicified, and parts of the original plain surface are capped by silicified rock and also by ferruginous sediments and ironstone derived from weathering of the limestone. Sink holes and caves are numerous and little water flows in creeks upstream from the Blue Waterhole.

Fossils are abundant in many places between Spencer's (White's) Hut and Jones' Hut. Brachiopods, stromatoporoids and corals are most prominent, but some gastropods are found towards the base of the formation, also bryozoa and nautiloids. Large bivalves occur in narrow beds north of Blue Waterhole Saddle and north-east of Coolamine.

Conchidium strictum is widespread and abundant, and, with *Favosites*, *Striatopora* and (probably) *Pycnostylus*, gives a Silurian age to the formation.

In the Blue Waterhole area the limestone is very granular and lacks well-preserved fossils.

(*b*) *Blue Waterhole Beds.*

These beds overlie the Cooleman Limestone and occur in a large, faulted basin around Coolamine and in two smaller outcrops north and south of the Cooleman Gorge.

At Harris' Dam the lowest beds of the basin structure appear to be interbedded with the limestone. They are micaceous siltstones or fine-grained sandstones, containing flat lamellibranchs and traces of nautiloids. Dark, banded cherts with shales and siltstones overlie the basal beds on Cave Creek, south of Coolamine. Slump structures are common in this locality, and the shallow-water origin of some of the beds is shown by mud-cracks at several horizons.

Above these rocks are more siltstones with narrow beds of black chert containing irregular cavities, representing moulds of corals such as *Heliolites*. A compact sandstone outcrops in the centre of the basin, south of Coolamine. The formation's maximum thickness of about 2,000 feet is in this area.

Isolated outcrops of shales and cherts which overlie the Cooleman Limestone north of the Blue Waterhole have been correlated with the same formation. From siltstone in one of these outliers small nautiloids have been collected.

On either side of Cooleman Gorge a formation of bedded cherts with overlying sandstone dips gently off the Cooleman Limestone.

The cherts are rhythmically bedded and show differential weathering (Pl. iv, fig. 6). They are highly fossiliferous with corals, both rugose and tabulate, predominating and show varying degrees of silicification. Similar rocks lie between the Pocket Beds and a massive limestone along Blue Waterhole Creek west of its junction with the Goodradigbee River.

From these cherts *Favosites*, *Striatopora*, *Hercophyllum*, ? *Thamnopora* and (probably) *Mycophyllum* have been collected.

(*c*) *Pocket Beds.*

The Pocket Beds, named by Newbery (1956), consist of shales, slates, limestones, cherts and tuffs, which outcrop in the Goodradigbee Valley north of Pocket Saddle.

They are found in two areas, separated by younger dacite. In the more southerly area, slates and phyllites are the main rock types, with some bedded tuffs and a thin discontinuous bed of limestone. They are bounded on the east by Nungar Beds and on the west by younger dacite.

The slates are buff-coloured, highly cleaved and in places strongly jointed, resulting in splintery fragments. Bedding planes are more obvious than in the Nungar Beds.

The limestone of the southern area is also highly cleaved, but contains corals, including *Propora* sp., crinoid stems and small ? Pentamerids. The only fossils recovered from the slates were a single trilobite pygidium and some poorly-preserved brachiopods.

Because of doubt as to the base and top of the formation in this area a sequence has not been established.

Further downstream the stratigraphic relations are clearer as cleavage diminishes and the proportion of limestone and chert increases. Here the Pocket Beds have been folded into a plunging anticline.

Slates, showing clearly the relation between bedding and cleavage, occur in the core of the fold. On the north-west limb thin limestones are interbedded with slate at a higher horizon and predominantly slaty strata are followed by cherty limestones with minor amounts of slate. Both rock types contain abundant fossils — corals in the limestones and brachiopods (including *Conchidium* and Stropheodontids) in the slates. Trilobite pygidia have been found in both. *Striatopora* sp., *Entelophyllum yassense*,

Plasmopora heliolitoides, Hercophyllum aff. *shearsbyi, Favosites* and *Heliolites* have been determined from an horizon near the top of the Pocket Beds north-east of Black Mountain. In addition, there are gastropods, Stropheodontids and straight conical nautiloids.

(*d*) *Wilkinson Limestone.*

At the top of the Pocket Beds are shales, overlain by cherts of the Blue Waterhole Beds or by a massive limestone where the cherts thin out completely. The limestone formation, which might be termed Wilkinson Limestone, is exposed in a steep-sided gorge (Wilkinson's Cliffs, Pl. iv, fig. 4) and is separated from the Cooleman Limestone by a felsitic intrusion.

The two limestones have previously been mapped as a continuous bed (Walpole, 1952), but the dowstream outcrop is now considered a higher horizon, because it overlies Blue Waterhole Beds (Pl. iv, fig. 3), whereas the Cooleman Limestone underlies these beds.

The only recognizable fossil collected from this limestone is a small, solitary rugose coral of an acanthophyllid type, which may be Upper Silurian or Lower Devonian.

? Devonian.

Lavas of acid and intermediate composition form some of the wooded ranges bordering the Cooleman Plain and remnants rest unconformably on Silurian sediments on the plain and on the edges of the Goodradigbee Valley. Angles of dip are gentle and their sheet-like form is indicated by their distribution, occasional columnar jointing (Pl. iv, fig. 5) and flow structures. As these lavas are post-Silurian and have been gently folded, their age may lie between Devonian and Permian. Lithologically similar dacites (Snowy River Porphyries) of probable Lower Devonian age (David, 1950) are known from eastern Victoria.

(*a*) *Rhyolite.*

A white rhyolite, porphyritic in quartz and orthoclase, underlies dacite on the north-east side of Gurrangorambla Range near Harris' Hut and forms a small outcrop south of Spencer's Hut. It has not been found beneath dacite on Cooleman Plain; being more viscous, it probably did not flow so far.

(*b*) *Kelly's Plain Dacite.*

Dacite is the most widely distributed lava and has been named by Newbery (1956), who studied it on Kelly's Plain, south of the Murrumbidgee River. It extends northwards, covering most of Currango Plain, and forms the lower parts of the Gurrangorambla Range near Harris' Hut. Outliers are found overlying Silurian limestone on Cooleman Plain and a similar rock occurs north of Pocket Saddle.

Bedded rocks which are probably acid to intermediate tuffs are associated with the dacite in the Gurrangorambla Range and interbedding of tuffs and several dacite flows has given rise to terraces on the spurs.

The dacite behaves like a flow rather than an intrusive, except for the occurrence north of Pocket Saddle where similar dacitic rocks are found in narrow tongues associated with the Pocket Beds. These are strongly cleaved and extend down into the Goodradigbee Valley. Quite possibly they are feeders to the flows or are epi-Silurian intrusives which have not reached the surface.

(*c*) *Rolling Grounds Andesite.*

An augite-andesite which, because of its persistent occurrence about the 4,200-foot level, is thought to be the youngest of the lavas, has been termed the Rolling Grounds Andesite.

It occurs on the Rolling Grounds Spur and on the Cooleman Plain south and east of Coolamine. No relations between it and other Devonian lavas have been noted.

The rock is a typical grey porphyritic andesite, and shows flow structure and columnar jointing. Occasionally a little quartz is present, indicating its dacitic affinity.

Intrusive Rocks.

Gingera Granite.

Only the western boundary of this granite was mapped for several miles along the eastern side of the area. It is probably continuous with the granite which makes the high peaks of Gingera, Bimberi and Morgan along the western boundary of the Australian Capital Territory.

Lithologically, the types examined resemble rocks of the Murrumbidgee bathylith, which is generally thought to be of Late Silurian age. The main type is a biotite-granite which exhibits slight foliation with trend approximately parallel to that of the cleavage of the country rocks (Nungar Beds). Some muscovite aplite occurs along the margin north of Oldfield's Hut.

Black Mountain Granite and Related Granodiorites.

Black Mountain is composed almost entirely of pink granite, coarse and felspathic along the lower western slopes, grading upwards into porphyritic pink granite, with a fine-grained pink acid granite at the summit. No contacts with surrounding rocks are exposed; granophyre adjoins it on the west and it is probably faulted against Pocket Beds on the east. The variation from base to summit suggests that the present summit is not far below the original roof of the stock.

Porphyritic pink granite is also found on the northern side of Blue Waterhole Creek, associated with marginal granite porphyry.

In the north-west of the area examined, granite, granodiorite and granodiorite porphyry outcrop near the U-bend in Cave Creek and in the Gurrangorambla Range. The former intrusion has converted calcareous sediments of Blue Waterhole Beds to calc-silicate hornfelses. Near its contact with dacite it becomes darker and more fine-grained, and appears to grade into the dacite.

The granodiorite intrusion to the west is small, and grades southwards into a larger mass of diorite. Here also the granodiorite is separated from the dacite by rocks with texture and mineralogy intermediate between the two. A larger mass of granodiorite forms most of the wooded ridge west of Coolamine.

All these intrusions, with the related diorite described below, appear to be later than the Silurian sediments and are either associated with the extrusion of dacite or closely following it. They may be assigned to the late Middle Devonian Tabberabberan epoch.

Diorite.

The main dioritic intrusion lies to the east and south-east of Blue Waterhole Saddle. It adjoins dacite to the south (with a transitional hybrid rock at one locality) and granophyre elsewhere, and is connected by a narrow tongue to a granodiorite-granodiorite-porphyry mass on the northern side of Seventeen Flat.

It intrudes the south-eastern tip of the Cooleman Limestone, producing some interesting contact rocks, including vesuvianite-bearing types. The diorite itself is epidotized near the contact.

Much variation in texture and some variation in composition are shown by this intrusion. Felspathic veins and irregular areas containing elongated amphibole needles also occur.

Another dioritic intrusion appears to intrude dacite and rhyolite in the range west of Harris' Hut. In each case field evidence (such as variation in the diorite towards the contact) suggests that the diorites intrude the dacites, despite the lack of evidence of any former substantial cover.

Gurrangorambla "Granophyre".

This name was originally given to the pink, felsitic rock with sparsely distributed felspar and ferromagnesian phenocrysts which makes up much of the east-west portion of Gurrangorambla Range.

The western part of this mass slopes east-south-east from Tom O'Rourke's Peak, falling 1,000 feet to plain level in a little over a mile. Elsewhere it behaves like a subhorizontal sheet.

A similar rock, with signs of flow-structure, borders the granite on the western slopes of Black Mountain and occurs to the south-east, where it is traceable into dykes which cross the Goodradigbee River.

The texture of the rocks so far examined is not truly granophyric, with irregular quartz-felspar intergrowths forming small spherical masses. There is no conclusive evidence to show whether the "granophyre" is extrusive or intrusive.

Minor Intrusions.

Fine-grained, acid dykes intrude the limestone on Cooleman Plain, but have had very little effect on it. Some show marked flow structure parallel to their walls, and most contain pyrite. Similar rocks intrude the limestone south of Cooleman Gorge.

Acid dykes up to 100 yards wide and a mile or more in length are found in the Goodradigbee Valley east of Black Mountain. They, and a third, shorter dyke, radiate from a hill of granophyre.

Andesitic intrusives, in the form of small dykes and sills, occur at a number of places throughout the area, but basic dykes are relatively rare. Most of the latter are dolerites.

Structural Geology.

In this section the structure of each of the three groups — Ordovician, Silurian and Devonian — will be discussed in turn, as each group has different structural characteristics, which may be related to the Benambran, Bowning and Tabberabberan orogenies respectively.

The overall picture is that of a major synclinal structure, with Silurian and Devonian rocks preserved between long north-south trending belts of Ordovician metasediments and granite.

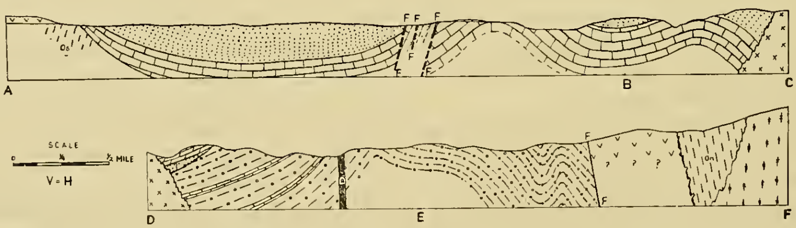
Ordovician.

Little information is available on the structure of the Nungar Beds in this area, as only their margin was mapped. The beds have been strongly folded, and the folds may be isoclinal. Dips of bedding planes are steep, mostly to the east, and cleavage planes dip in the same direction.

Silurian.

(a) Cooleman Limestone and Associated Beds.

The Cooleman Limestone occupies an irregular area due to its varying thickness and folding. At its western extremity the thickness is only about 400 feet, but it appears to thicken considerably to a maximum of 2,000 feet in the south-east (Text-fig. 1).



Text-fig. 1.—Sections along the lines ABC and DEF on the map (Plate iii).

West of a north-south line through Blue Waterhole Saddle, dips in the Cooleman Limestone and the overlying beds suggest a basin structure, but this is complicated by an anticline in the limestone west of Spencer's Hut (Pl. iv, fig. 2) and abrupt changes in strike and dip near the Blue Waterhole. Evidence of strong faulting is seen at the boundary between Cooleman Limestone and Blue Waterhole Beds north-west of Spencer's Hut.

The eastern prolongation of the Cooleman Limestone down the gorge as far as the felsitic intrusion is also due to a broad anticline which strikes east-south-east and

plunges in that direction. Dips in the limestone and overlying cherts are gentle (about 10°) in the gorge except close to a fault on the south-east margin of the limestone, where a thin bed of overlying chert dips steeply to the south. This structure does not continue downstream, probably because of igneous intrusions with associated faulting.

Several minor folds and faults have been noted in the Blue Waterhole Beds, and numerous small faults intersect the limestone along Cave Creek and in Cooleman Gorge. Over most of its outcrop the limestone exhibits strong jointing, which locally passes into a cleavage.

(*b*) *The Pocket Beds and Overlying Strata.*

The Pocket Beds on the eastern side of Black Mountain have been folded into an anticline with axial strike varying from north-south to north-east — south-west near the Goodradigbee River, and plunging to the north-east. North of this axis most dips are northerly, and the overlying cherts and Wilkinson Limestone dip in this direction. South of the anticlinal axis the beds assume a north-south strike and easterly dip. A synclinal fold appears further east.

The structure is outlined, particularly in the northern limb, by cherty limestones which are interbedded with the slates. Bedding and cleavage are easily distinguishable in the northern outcrop, but in the southerly outcrop of the Pocket Beds cleavage becomes more prominent and bedding less evident until, close to Pocket Saddle, the degree of dynamic metamorphism approaches that of the adjacent Nungar Beds.

The strike of the cleavage in the Pocket Beds varies as the strike of the bedding (i.e. from east-west in the north to north-south in the south), and may be up to 10–15 degrees different, but the dip of the cleavage is always steeper than the dip of the bedding. The direction of dip of the cleavage changes gradually on passing from the northern limit of the fold to the southern; the dip varies from southerly through south-easterly to easterly as the river is followed upstream.

In the Wilkinson Limestone extremely complex close folds are outlined by thin cherty layers in the cliff faces, but the bed, as a whole, does not seem to have been strongly compressed. It is likely that the folding was caused by movement prior to consolidation. Intraformational deformation caused by pene-contemporaneous slumping has been described in laminated siliceous limestones from Texas and New Mexico (Newell *et al.*, 1953).

? Devonian.

The structure of the ? Devonian lavas is in marked contrast to that of the older beds, in that they are mostly gently dipping or sub-horizontal. In this area, folding referable to the Tabberabberan orogeny seems to have been very slight. Probably at this time the dacite suffered shearing of variable intensity. This is best shown in the Pocket Saddle area, and all the occurrences of sheared dacite are close to slate boundaries, which may also be fault boundaries. Beds of jasper and silicified rock on the ridge between Pocket Creek and the Goodradigbee River suggest faulting, as does a wide zone of ironstone and silicified dacite between Howell's Peak and The Pockets Hut.

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EXPLANATION OF PLATES III-IV.

Plate iii.

Geological map of the Cooleman Caves district.

Plate iv.

1. Cooleman Plain, looking easterly from Jones' Hut. Open grassland is Cooleman Limestone, wooded ridge in mid-distance is granite and granodiorite. Bimberi Range (granite) on horizon.

2. Faulted anticline in Cooleman Limestone, Cave Creek, west of Spencer's Hut.

3. Cooleman Falls, Blue Waterhole Creek. Bedded rock in foreground is Blue Waterhole chert, underlying Wilkinson Limestone (upper right).

4. Wilkinson Limestone, Wilkinson's Cliffs. Granite outcrops on wooded hillside in background.

5. Columnar dacite, Currango Plain, south of Blue Waterhole Saddle.

6. Bedded cherts of the Blue Waterhole Beds near Spencer's Hut.